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SPECIFIC IMPULSE VALUES FOR HYDROGEN AND RDX

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PREFACE

In mid 1963 RAND became interested in propulsion by nuclear explosions (RM-3761-AEC Propulsion by Contained Nuclear Explosions (U) dated June 1963 and RM-3796-AEC Second Report on Propulsion by Contained Nuclear Explosions (U) dated July 1963). This study was carried out as a consequence of the above reports.

It is a contribution to a better understanding of the complex problems involved in the utilization of contained nuclear explosions for propulsion purposes.

SUMMARY

The purpose of this study is the parametric investigation of hydrogen and RDX as working materials in rockets propelled by contained nuclear explosions (Project HELIOS). Hydrogen, by virtue of its low molecular weight, is the prime working fluid of chemical rockets. RDX is a chemical explosive used in the construction of nuclear implosion devices. Chemically known as cyclomethylene-trinitramine or cyclonite, RDX has the empirical formula $C_3H_6O_6N_6$.

A two-part computational program was carried out for each compound. The results are presented in graphic form. The results of the first part of the program are presented in static form, i.e., by the conventional Mollier diagram, in which specific enthalpy is plotted against specific entropy, with cross plots of temperature, pressure, and molecular weight. The results of the second part are presented in dynamic form by a series of diagrams in which specific impulse is plotted against chamber pressure with chamber temperature and exhaust pressure as parameters.

The specific impulse of hydrogen heated by a nuclear explosion, neglecting fission products, may then be obtained by taking a linear combination of properly weighted specific impulse values for hydrogen and RDX.

ACKNOWLEDGMENTS

This study involved considerable machine computation. The efforts of the following RAND Physics Department staff members are gratefully acknowledged: Donald A. Brown, for his extensive programming and machine work; and Elizabeth J. Force, for her meticulous graphical presentation of the tabulated results.

CONTENTS

I. INTRODUCTION

The mechanics of computing the equilibrium compositions and thermodynamic properties of gas mixtures at various temperatures and pressures is well established. The procedure has been used at RAND in the study of various chemical and nuclear rocket propellants and ablating materials. The procedure for hydrogen is quite simple since only two chemical species, H and H_2, are involved. It is described in Ref. 1, which considers hydrogen as a nuclear rocket propellant. The procedure for RDX is somewhat more complicated since many chemical species based on the elements C, H, O, and N are involved. In this study 91 such species were taken into consideration. The general procedure and sources of information are described in Ref. 2, which considers polyamide resin (Nylon-6) as an ablating material. In the present report the computations of Ref. 1 for hydrogen were updated by extending the temperature range to 6000°K. The computations for RDX made use of the program and data employed in Ref. 2 and, as in the case of hydrogen, were carried out on the RAND JOHNNIAC computer.

The specific impulse values for hydrogen and for RDX were computed in accordance with the method described in Ref. 1, which assumes that the propellant gas, starting with a nonzero chamber velocity, maintains instantaneous chemical equilibrium as it expands isentropically through a de Laval nozzle.

II. RESULTS

The results of the first part of this study are presented graphically in Figs. 1 and 2, which are conventional Mollier diagrams for hydrogen and RDX in which specific enthalpy is plotted against specific entropy, with cross plots of temperature, pressure, and molecular weight. The temperatures range from $6000^{\circ}K$ to $300^{\circ}K$, while the pressures range from 10^{5} atm to 10^{-8} atm.

The results of the second part of this study are presented graphically in Figs. 3 through 7. In these figures specific impulse is plotted against chamber pressure for a series of chamber temperatures ranging from $3500^{\circ}K$ to $6000^{\circ}K$. Exhaust pressure, considered a fixed parameter in each of the figures, ranges from 10^{0} atm to 10^{-4} atm. Aside from the obvious fact that specific impulse increases with temperature, inspection of these figures shows that for each exhaust pressure a homologous family of curves is formed, each curve attaining a distinct maximum value for a specified chamber temperature.

Figure 8 is a synthesis of Figs. 3 through 7. Maximum specific impulse is plotted against chamber pressure for hydrogen and RDX with cross plots of chamber temperature and exhaust pressure. Comparison of corresponding isotherms shows that RDX is much less sensitive than hydrogen to change in exhaust pressure. Moreover, for a given set of chamber temperature and pressure values hydrogen and RDX attain their maximum specific impulse values at different exhaust pressures.

The effectiveness of contained nuclear explosions for rocket propulsion purposes (as envisioned in Project HELIOS) depends, to a large degree, on the specific impulse of the propellant gas which consists of a working fluid (hydrogen) and the nuclear explosion products (RDX). The contribution of the fission products to the over-all specific impulse value is considered to be negligible. Once the proper hydrogen-RDX ratio has been established from design considerations, the specific impulse of the propellant gas can be determined by taking a linear combination of specific impulse values

for hydrogen and RDX. The exhaust pressure irregularity noted above can be circumvented in the following manner. The maximum specific impulse for hydrogen is selected from Fig. 8 for the design conditions T_c, P_c, P_e. The specific impulse value for RDX is then selected, not from Fig. 8, but from one of the preceding figures which satisfies the design conditions.

As an example, suppose that the hydrogen-RDX weight ratio is 9:1 and that $T_c = 6000^oK$, $P_c = 10^{2.395}$ or 248 atm, and $P_e = 1$ atm. Then, from Fig. 8, I_{max} for hydrogen is 1663 sec. For the same temperature and pressure conditions Fig. 3 shows that the specific impulse for RDX is 471 sec. The specific impulse for the combination is, therefore, 1544 sec.

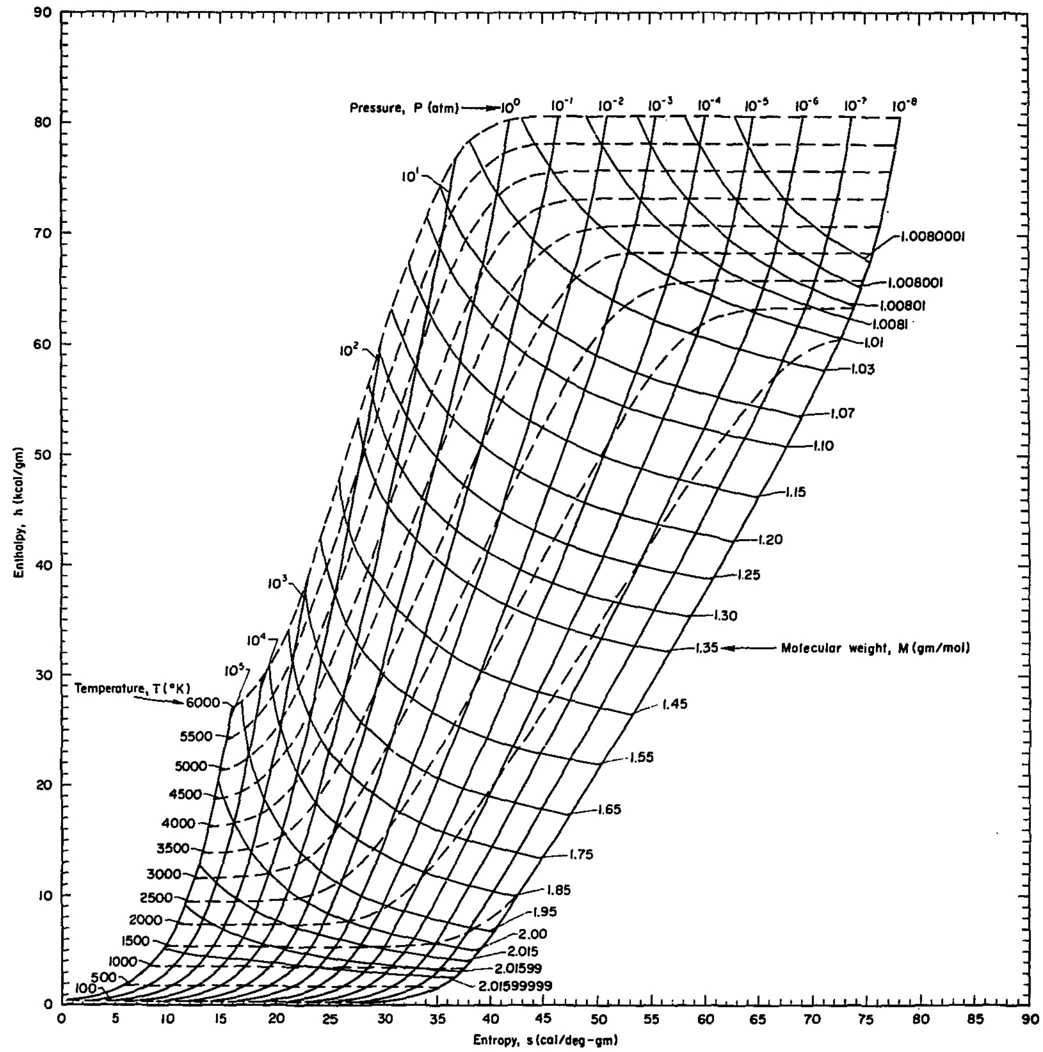

Fig. 1—Enthalpy versus entropy for hydrogen, with cross plots of temperature, pressure and molecular weight

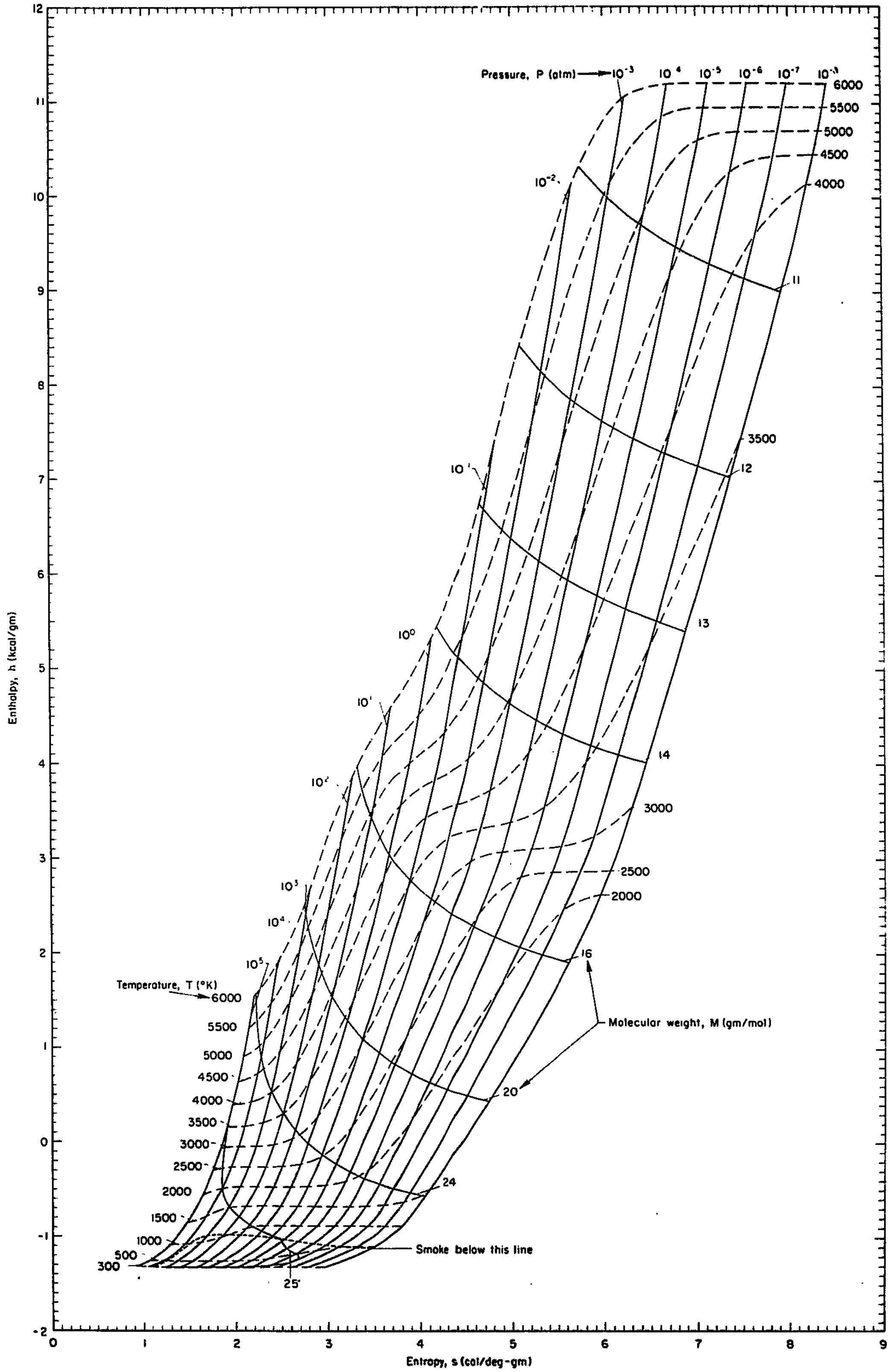

Fig.2—Enthalpy versus entropy for RDX, with cross plots of temperature, pressure and molecular weight

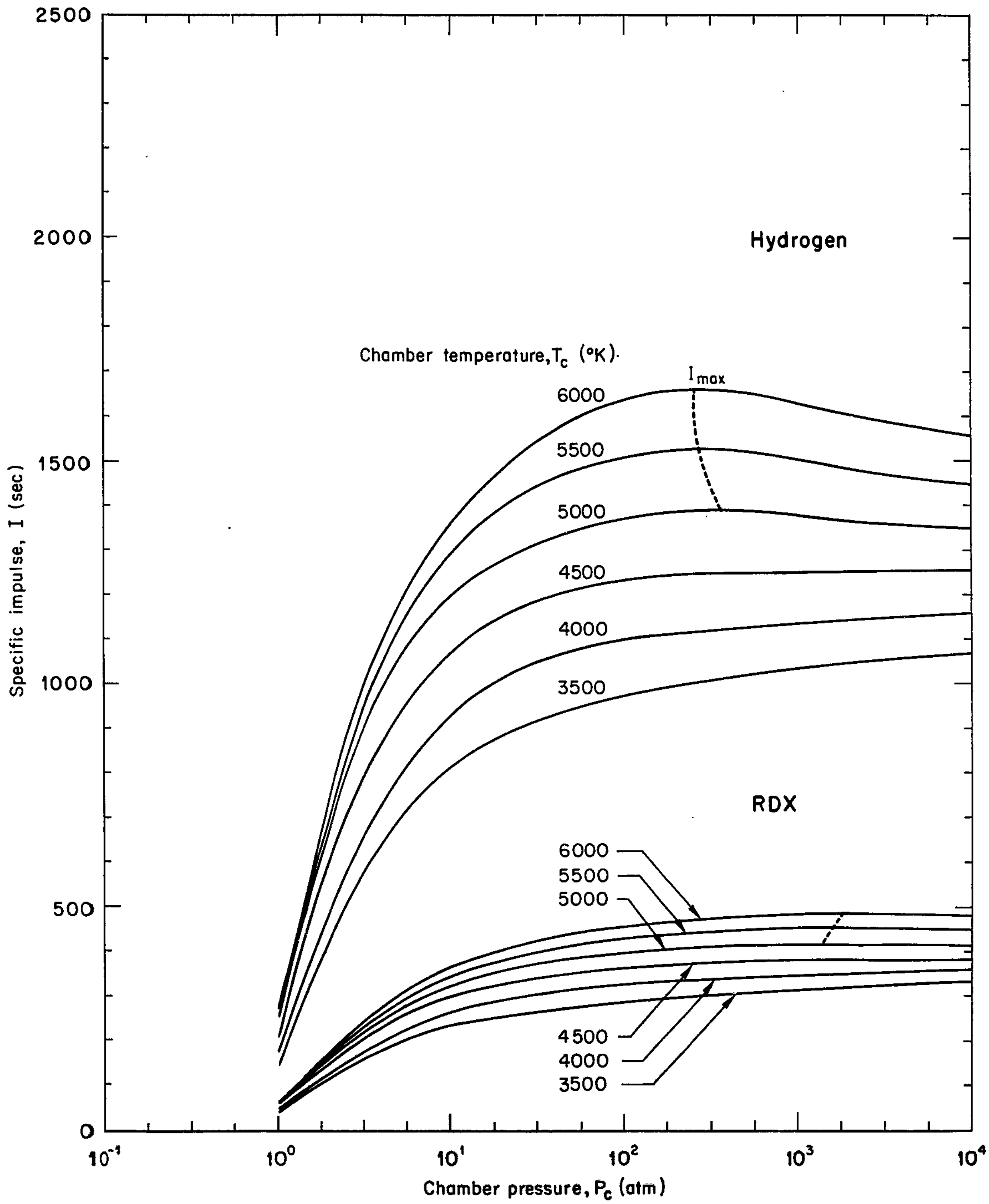

Fig. 3—Specific impulse versus chamber pressure for hydrogen and RDX at various chamber temperatures and an exhaust pressure of 1 atmosphere

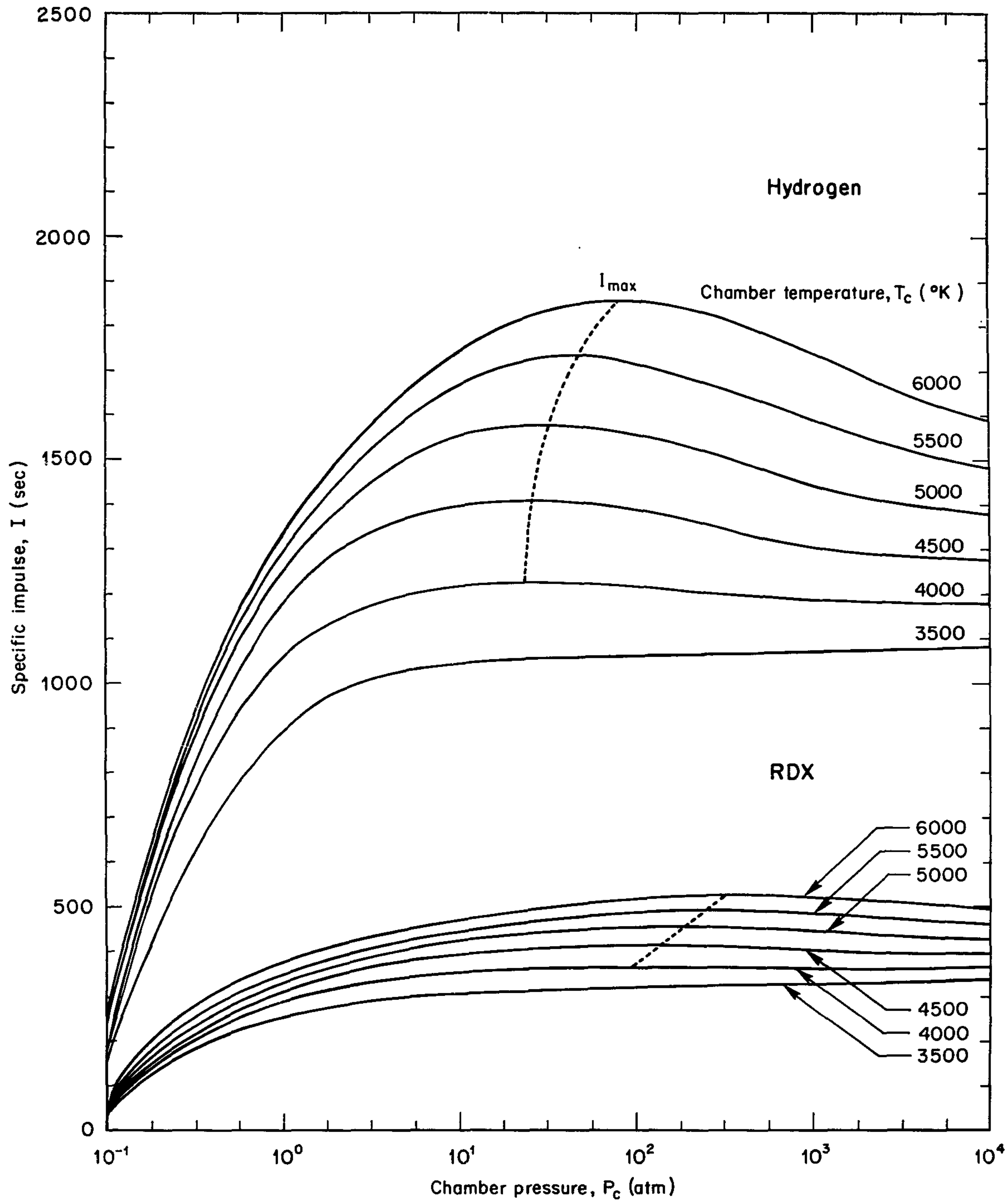

Fig. 4—Specific impulse versus chamber pressure for hydrogen and RDX at various chamber temperatures and an exhaust pressure of 10^{-1} atmosphere

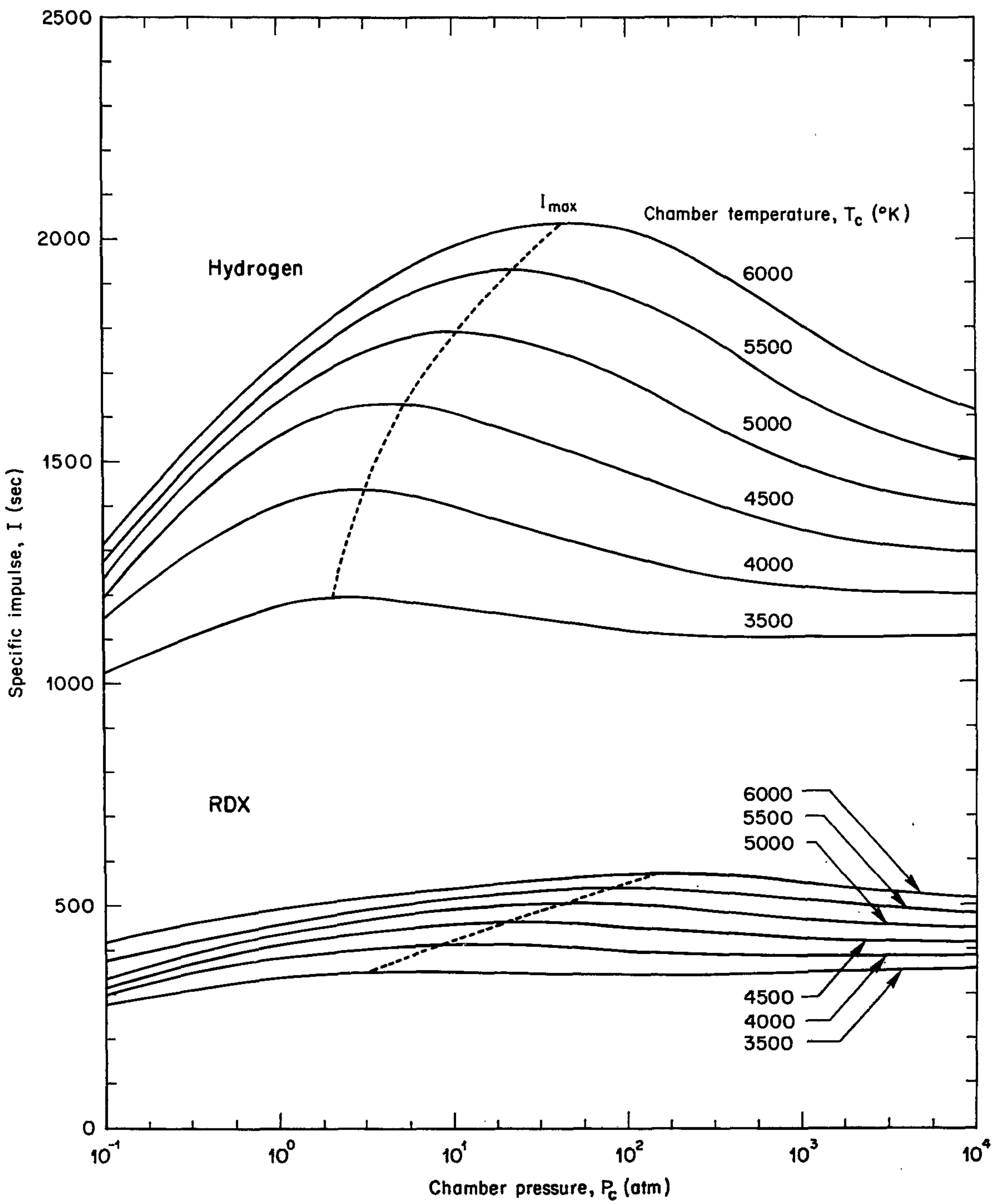

Fig. 5— Specific impulse versus chamber pressure for hydrogen and RDX at various chamber temperatures and an exhaust pressure of 10^{-2} atmosphere

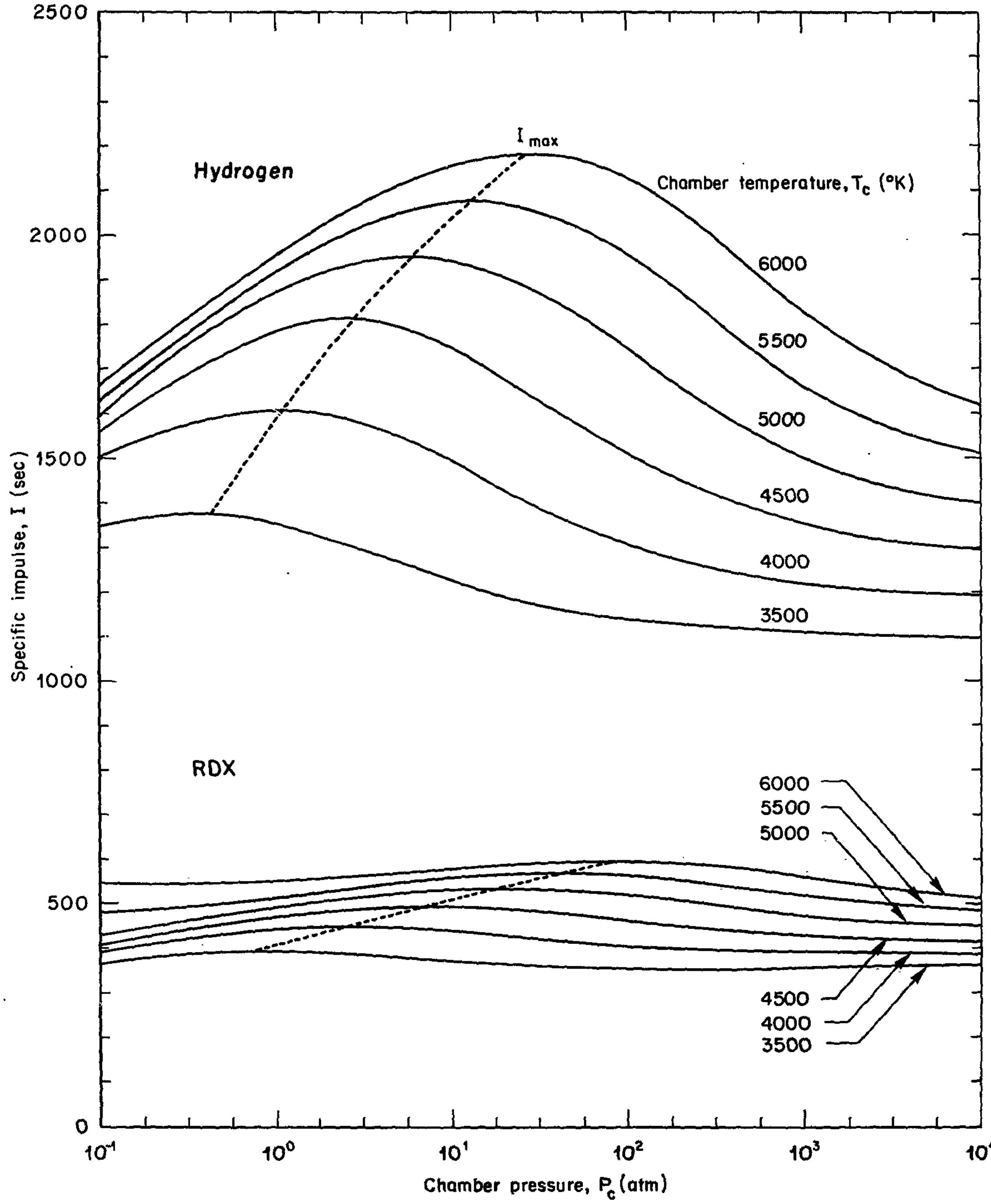

Fig. 6—Specific impulse versus chamber pressure for hydrogen and RDX at various chamber temperatures and an exhaust pressure of 10^{-3} atmosphere

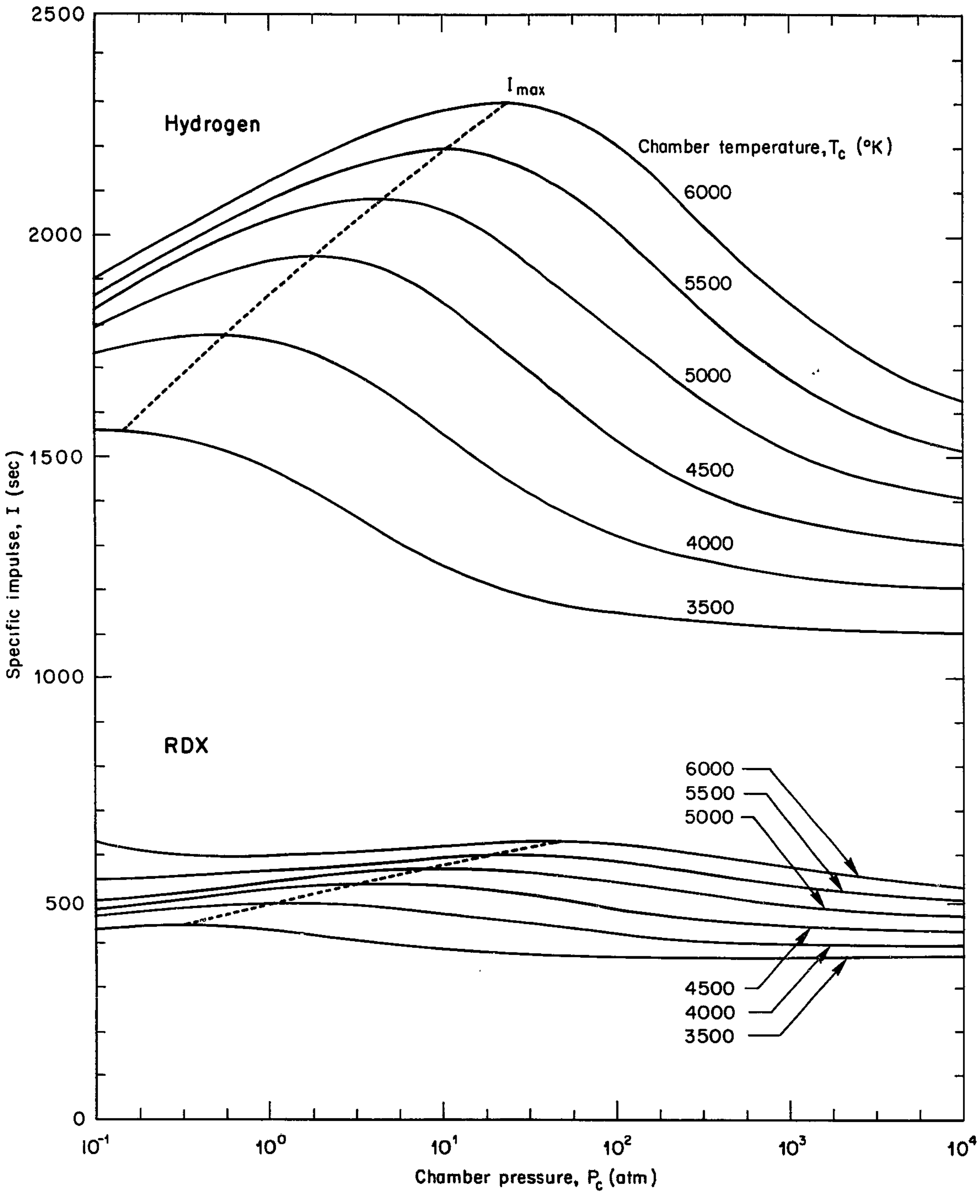

Fig. 7— Specific impulse versus chamber pressure for hydrogen and RDX at various chamber temperatures and an exhaust pressure of 10^{-4} atmosphere

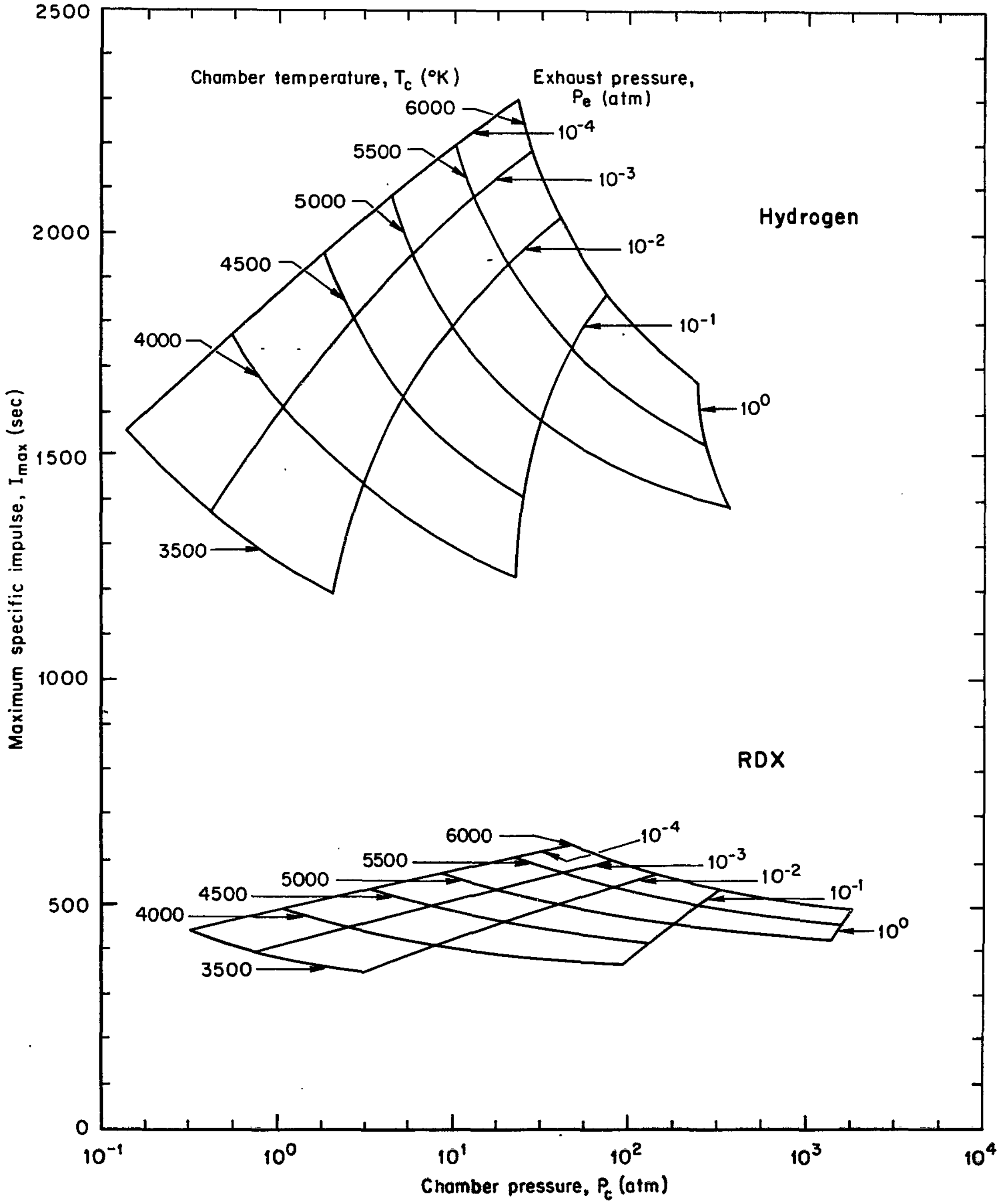

Fig.8—Maximum specific impulse versus chamber pressure for hydrogen and RDX at various chamber temperatures and exhaust pressures

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